Ruzigrass affecting soil-phosphorus availability

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Abstract – The objective of this work was to evaluate the effectiveness of ruzigrass (*Urochloa ruziziensis*) in enhancing soil-P availability in areas fertilized with soluble or reactive rock phosphates. The area had been cropped for five years under no-till, in a system involving soybean, triticale/black-oat, and pearl millet. Previously to the five-year cultivation period, corrective phosphorus fertilization was applied once on soil surface, at 0.0 and 80 kg ha^{-1} P_2O_5, as triple superphosphate or Arad rock phosphate. After this five-year period, plots received the same corrective P fertilization as before and ruzigrass was introduced to the cropping system in the stead of the other cover crops. Soil samples were taken (0–10 cm) after ruzigrass cultivation and subjected to soil-P fractionation. Soybean was grown thereafter without P application to seed furrow. Phosphorus availability in plots with ruzigrass was compared to the ones with spontaneous vegetation for two years. Ruzigrass cultivation increased inorganic (resin-extracted) and organic ($NaHCO_3$) soil P, as well as P concentration in soybean leaves, regardless of the P source. However, soybean yield did not increase significantly due to ruzigrass introduction to the cropping system. Soil-P availability did not differ between soluble and reactive P sources. Ruzigrass increases soil-P availability, especially where corrective P fertilization is performed.

Index terms: *Brachiaria ruziziensis*, *Urochloa ruziziensis*, cover crops, crop rotation, P cycling, phosphorus fractionation.

Efeito da braquiária sobre a disponibilidade de fósforo no solo

Resumo – O objetivo deste trabalho foi avaliar a eficácia da braquiária (*Urochloa ruziziensis*) em aumentar a disponibilidade de P, em solo de áreas fertilizadas com fosfatos solúveis ou reativos. A área havia sido cultivada em semeadura direta por cinco anos, em sistema de cultivo com soja, triticale/aveia-preta e milheto. Previamente ao período de cinco anos de cultivo, aplicou-se adubação corretiva de P à superfície do solo, com 0,0 ou 80,0 kg ha^{-1} P_2O_5, nas formas de superfosfato triplo ou fosfato Arad. Após esse período de cinco anos, as parcelas receberam a mesma adubação corretiva de antes, e a braquiária foi introduzida no sistema de cultivo no lugar das outras plantas de cobertura. Após o cultivo da braquiária, foram coletadas amostras de solo, na camada 0–10 cm, e submetidas ao fracionamento de P. A soja foi cultivada em seguida, sem adubação fosfatada no sulco de plantio. A disponibilidade de P nas parcelas com a braquiária foi comparada àquelas com vegetação espontânea, por dois anos. O cultivo da braquiária aumentou os teores de P inorgânico (extraído com resina) e orgânico ($NaHCO_3$) no solo, bem como o conteúdo de P nas folhas da soja, independentemente da fonte de P utilizada. No entanto, a produtividade da soja não aumentou significativamente pela introdução da braquiária ao sistema de cultivo. A braquiária aumenta a disponibilidade de P no solo, especialmente nas áreas com adubação fosfatada corretiva.

Termos para indexação: *Brachiaria ruziziensis*, *Urochloa ruziziensis*, cultivos de cobertura, rotação de culturas, ciclagem de P, fracionamento de fósforo.

Introduction

In tropical and subtropical regions, most soils have low P availability and high adsorption capacity, making it necessary to repeatedly apply P fertilizers to soil in order to sustain high crop yields. Water-soluble P is rapidly transformed into P forms that are less or completely unavailable to plants. Soil organic P (Po) often accounts for 50–70% of the total P in soils, and it is mainly present as inositol penta- and hexaphosphates (Borie & Rubio, 2003). These organic forms must be mineralized to inorganic P (Pi), such as orthophosphate (ortho-P), to allow its uptake by plants. Therefore, soil-P fractionation is fundamental to understand P bioavailability in agriculture areas.

Accumulation of P in plant tissue may reduce its losses in soil by chemical fixation or occlusion. Cover crops are usually more efficient to absorb less labile P forms and, therefore, their introduction into cropping systems may improve P availability to plants, since ortho-P – which is readily available to them – is released back to the soil by the mineralization of those tissues (Pavinato & Rosolem, 2008).

Cover crops such as black oat (*Avena sativa*), velvet bean (*Mucuna pruriens*), common vetch (*Vicia sativa*), lupins (*Lupinus albus)*, and the ones from *Urochloa* genus (Syn. *Brachiaria*) have been extensively studied as to their efficiency to cycle P. However, their P cycling potential in agriculture ecosystems are not fully understood. Moreover, the effects of cover crop residues on soil-P transformations and availability to succeeding crops are still unclear.

Ruzigrass (*Urochloa ruziziensis*) has been widely used in crop rotation and crop-livestock integrated systems in Brazil because of its good adaptation to low-fertility soils, high yield potential, good forage quality, and ready desiccation (Garcia et al., 2008). Furthermore, this tropical grass has been reported to increase P apparent recovery in cropping systems (Sousa et al., 2010). Increased P availability by cover crops has been observed under no-till because organic acids, stemming from organic matter breakdown, can compete with orthophosphate for adsorption sites (Pavinato et al., 2009). In addition, enhanced mineralization of organic P from the added plant residues increase soil available P (Erich et al., 2002).

Phosphorus pools in soil can be characterized by sequential chemical extraction procedures (Hedley et al., 1982). Ruzigrass efficiency in acquiring less soluble soil P and its P cycling potential are important information for managing P fertilization in soils with high P fixing capacity. If ruzigrass could enhance soil-P bioavailability, by uptaking less soluble forms of this nutrient and returning it to the soil by mineralization, it could enhance the agronomic efficiency of less soluble phosphates, such as the reactive Arad and Gafsa rock phosphates, which may be cheaper than soluble sources, but usually provides lower yields in the first cropping year (Horowitz & Meurer, 2004).

The objective of this study was to evaluate the effectiveness of ruzigrass (*Urochloa ruziziensis*) in enhancing soil-P availability in areas fertilized with soluble or reactive rock phosphates.

Materials and Methods

The experiment was established in 1998, in Botucatu, SP (22º51'S, 48º26'W, at 840 m altitude), on a Rhodic Hapludox (Soil Survey Staff, 2010), sandy loam, with 670 g kg^{-1} sand, and 210 g kg^{-1} clay. A crop rotation system consisting of triticale (X *Triticosecale* Wittmack) or black oat (*Avena stringosa*), in fall-winter, pearl millet (*Pennisetum glaucum*) in the spring, and soybean (*Glycine max*) in the summer was conducted under no-till from 1998 to 2006. In 1998 and 2001, the experiment received a corrective phosphorus fertilization, broadcasted on soil surface at 0 (control) and 80 kg ha^{-1} P_2O_5 (as total P), as triple superphosphate or Arad reactive rock phosphate. Soybean was fertilized (all plots) in the furrows during this period (1998–2006), receiving 750 kg ha^{-1} P_2O_5 (annual average of ~ 95 kg ha^{-1} P_2O_5). Selected chemical characteristics of soil in March 2006 are shown in Table 1.

In 2006, the cropping system was changed to ruzigrass and fallow, instead of triticale or black oat and pearl millet. In April 2006, the area received another corrective phosphorus fertilization (3rd application), with the same doses and sources as before, applied to the same plots. Triple superphosphate had 179 g kg^{-1} P, 92 g kg^{-1} Ca, and 10 g kg^{-1} S; and the reactive Arad phosphate had 139 g kg^{-1} P, 264 g kg^{-1} Ca, and 10 g kg^{-1} S. The fertilizers were broadcasted on soil surface; and ruzigrass was planted (without fertilizers) in half of the plots, at the seed rate of 30 kg ha^{-1} (32% of viable seeds). Half of the plots were left with spontaneous vegetation. Ruzigrass and the spontaneous vegetation were desiccated 215 days after emergence (DAE) using glyphosate at 2.88 kg ha^{-1} (a.e.). The impact of ruzigrass on the cropping system was studied in 2006–2007.

To estimate forage dry matter yield, plant residues were sampled at six random sites per plot, using a 0.25 m^2 (0.5x0.5 m) wooden frame, and dried in an air-forced oven at 60ºC, for 72 hours. Samples from the residues were weighed, and subsamples were analyzed for N, P, K, Ca and Mg concentrations. Nitrogen was determined by sulfuric acid digestion and steam distillation. P, K, Ca, and Mg were determined using a atomic absorption spectrometer AA-7000, (Shimadzu Scientific Instruments, Kyoto, Japan), after wet acid digestion.

In November 2006, six soil samples were randomly taken from each plot with an auger, at two depths (0–5 and 5–10 cm), and combined into a composite sample

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per depth, for analysis. Soil pH was determined in 0.01 mol L^{-1} $CaCl_2$ at 1:2.5 soil/solution (w/v) ratio using a pH meter DM-22 (Digimed, São Paulo, SP, Brazil), and organic matter was determined by the Walkley-Black method, as described by Raij et al. (2001).

After ruzigrass desiccation (November 2006), soybean 'BRS 184' was mechanically planted over the standing cover crop residues, in rows 0.45 m apart, at a final average stand density of 320,000 plants per hectare. No phosphate fertilizer was applied to seed furrows. After planting, 45 kg ha^{-1} K_2O was broadcasted as potassium chloride to all plots. Soybean was harvested 128 days after plant emergence. At full flowering stage, 30 recently matured soybean leaves per plot were sampled – the third or fourth fully developed trifoliate from the top –, washed, dried at 60°C for 48 hous, and ground for P analysis, as described for ruzigrass residues.

Soil P was fractioned according to Hedley et al. (1982), with modifications proposed by Condron et al. (1985). To estimate available P, 0.5 g soil was shaken in water suspension for 16 hours, on a horizontal shaker (end-over-end) with one strip of the anion exchange resin membrane Anionic Resin 204SZRA-88091668 (GE Water & Process Technologies, Trevose, PA, USA). Pi and Po fractions were extracted with 0.5 mol L^{-1} $NaHCO_3$ (pH 8.5); then, Pi (oxide-bound P) and Po fractions were extracted with 0.1 mol L^{-1} NaOH; following, calcium-bound P (Ca-P) was extracted with 1.0 mol L^{-1} HCl; and finally, Pi and Po fractions were extracted with 0.5 mol L^{-1} NaOH. The concentration of P in the extracts was determined by the ascorbic-reduction molybdate blue colorimetric method (Murphy & Riley, 1962). All samples were analyzed in triplicate. According to Hedley fractionation, the correspondent P fractions are: resin-Pi, readily inorganic P available to plants; 0.05 mol L^{-1} $NaHCO_3$-Pi, available Pi to plants; 0.1 mol L^{-1} NaOH-Pi, oxide-bound P; and 1.0 mol L^{-1} HCl-Pi, bound Pi to Ca-phosphates and Pi which is occluded within sesquioxides.

A randomized complete block design was carried out with four replicates, in a 3x2 factorial arrangement, with three P initial treatments: no P; 80 kg ha^{-1} P_2O_5 as triple superphosphate; and 80 kg ha^{-1} P_2O_5 as reactive phosphate; with or without ruzigrass. Data for each soil depth were analyzed separately. Plots were 5.0x8.0 m, and blocks were set 9.0 m apart from each other to allow machine traffic. Results were subjected to statistical analyses using SAS for Windows 6.11, version 8.2 (SAS Institute, Cary, USA), through the GLM procedure. Means were compared by the LSD test, at 5% probability.

Results and Discussion

Treatments did no differ as to ruzigrass average dry matter yield (4,644 kg ha^{-1}) and P content in plant tissue (2.1 g kg^{-1}). The average contents of N, K, Ca, and Mg tissue were 12.7, 18.0, 6.3, and 4.3 g kg^{-1}, respectively, which also were not influenced by P fertilization treatments. Nutrient contents were within the adequate range reported by Malavolta et al. (1997).

Neither P treatments nor ruzigrass cultivation affected soil pH and organic matter contents (Table 1). However, phosphate broadcast on soil surface, after several years of no-till, generally increased available P, irrespective of P source, mostly in the 0–5 cm depth, except for 0.5 mol L^{-1} $NaHCO_3$-Pi extractor (Table 2). Organic acid exudation by plant roots possibly affects P movement in the soil profile (Pavinato & Rosolem, 2008). In the present study, this movement

Table 1. Selected chemical characteristics of the soil prior to the field trial (March 2006).

Treatment[(1)]	pH $CaCl_2$	SOM (g kg^{-1})	P-resin (mg kg^{-1})	H+Al	K	Ca	Mg	CEC	BS (%)
				----------(mmol$_c$ kg^{-1})----------					
				0–5-cm soil depth					
0 kg ha^{-1}	4.9	22.5	20.2	26.9	1.4	19.2	7.4	54.8	50.9
80 kg ha^{-1} reactive phosphate	5.1	23.7	27.0	25.8	1.7	15.4	7.6	50.4	48.8
80 kg ha^{-1} soluble phosphate	5.0	24.1	26.4	25.5	1.3	17.6	7.4	51.8	50.7
				5–10-cm soil depth					
0 kg ha^{-1}	4.7	20.3	14.1	30.4	0.9	13.8	5.3	50.4	39.6
80 kg ha^{-1} reactive phosphate	4.8	20.3	13.7	29.6	0.8	10.6	4.6	45.6	35.0
80 kg ha^{-1} soluble phosphate	4.7	20.6	13.3	29.5	1.1	12.5	5.1	48.3	38.8

[(1)]Phosphorus treatments were applied in 1998 and 2001, totaling 160 kg ha^{-1} P_2O_5, prior to the third application in 2006. SOM, soil organic matter; CEC, cation exchange capacity; BS, soil base saturation.

depended on P source and on the presence of ruzigrass (Table 2 and 3).

Ruzigrass increased resin-extractable P (available P) in the soil at both depths where P treatments were applied (Table 2). At the 0–5 cm depth, forage increased available P by 13%, when reactive rock phosphate (RRP) was used, and by 21% when soluble phosphate fertilizer was used. Higher effect of ruzigrass in available P was observed at the 5–10 cm soil depth, where the relative values increased 76 and 77%, respectively. Available P in the control plot was not affected by the cultivation of the cover crop.

Soil-P fractionation showed that ruzigrass had minimal effects on Pi as extracted by 0.1 mol L^{-1} NaOH, regardless of P fertilizer levels or sources (Table 2). It had a significant effect on HCl-Pi, which increased 40% at the 0–5 cm soil layer in plots with RRP, and decreased 34% at the 5–10 cm layer in plots with soluble fertilizers. The introduction of ruzigrass to the cropping system significantly increased extractable-Po (0.5 mol L^{-1} $NaHCO_3$) at the 0–5 cm soil layer, both in the control and in the treatment which received water-soluble P (Table 3). At the 5–10 cm soil layer, only plots which received a soluble P source showed a significant increase in extractable-Po due to ruzigrass cultivation.

No changes occurred in other soil-Po fractions due to ruzigrass cultivation, except for NaOH-Pi, a less labile form as compared with resin extracted P, which was increased at both the 0–5 and 5–10 cm soil layers (Table 2).

Ruzigrass cultivation significantly interacted with phosphate treatments (Table 3) as to available P, HCl-Pi, and 0.5 mol L^{-1} NaOH-Pi, at both soil depths.

Table 2. Mean contents (mg kg^{-1}) from different fractions[(1)] of inorganic P (Pi), at different soil depths, as affected by surface broadcast application of phosphorus sources, and by *Urochloa ruziziensis* cultivation[(2)].

Treatment	Resin-Pi[(1)]		0.5 mol L^{-1} $NaHCO_3$-Pi		0.1 mol L^{-1} NaOH-Pi		1.0 mol L^{-1} HCl-Pi		0.5 mol L^{-1} NaOH-Pi	
	With *U. ruziziensis*	Without *U. ruziziensis*	With *U. ruziziensis*	Without *U. ruziziensis*	With *U. ruziziensis*	Without *U. ruziziensis*	With *U. ruziziensis*	Without *U. ruziziensis*	With *U. ruziziensis*	Without *U. ruziziensis*
					0–5-cm soil depth					
0 kg ha^{-1}	10.8aB	10.5aB	34.8aA	22.9bA	27.4aB	30.2aB	14.4aB	13.3aB	23.2aB	29.4aA
80 kg ha^{-1} reactive phosphate	49.0aA	43.1bA	30.7aA	23.7bA	34.6aA	33.2aAB	35.6aA	25.4bA	47.1aA	18.9bA
80 kg ha^{-1} soluble phosphate	46.2aA	38.1bA	36.1aA	28.0bA	32.8aA	37.5aA	23.6aA	20.4aA	26.3aB	25.2aA
					5–10-cm soil depth					
0 kg ha^{-1}	10.9aB	13.1aA	31.8aA	26.1bA	25.0aB	29.6aA	15.6aA	13.5aB	17.3bB	26.2aA
80 kg ha^{-1} reactive phosphate	23.7aA	13.4bA	30.1aA	29.4bA	37.5aA	33.0aA	17.0aA	20.2aA	40.2aA	17.0bA
80 kg ha^{-1} soluble phosphate	28.7aA	16.2bA	34.0aA	27.1bA	34.0aA	28.1aA	17.0bA	22.9aA	16.8bB	28.8aA

[(1)]P fractions as in Hedley et al. (1982) fractionation: resin-Pi, readily available Pi; 0.05 mol L^{-1} $NaHCO_3$-Pi, available to plants; 0.1 mol L^{-1} NaOH-Pi, oxide bound-Pi; 1.0 mol L^{-1} HCl-Pi, Pi bound to Ca-phosphates, or occluded within sesquioxides.[(2)]Means followed by equal letters, lowercase between ruzigrass treatments and uppercase between P treatments, do not differ by LSD test, at 5% probability.

Table 3. Mean contents (mg kg^{-1}) from different fractions[(1)] of organic P (Po), at different soil depths, as affected by surface broadcast application of phosphorus sources, and by *Urochloa ruziziensis* cultivation[(2)].

Treatment	0.5 M $NaHCO_3$-Po		0.1 M NaOH-Po		0.5 M NaOH-Po	
	With *U. ruziziensis*	Without *U. ruziziensis*	With *U. ruziziensis*	Without *U. ruziziensis*	With *U. ruziziensis*	Without *U. ruziziensis*
			0–5-cm soil depth			
0 kg ha^{-1}	15.8aA	3.3bB	33.5aB	33.2aB	44.7aA	41.7aA
80 kg ha^{-1} reactive phosphate	19.7aA	15.2bA	38.7aB	42.6aA	48.1aA	50.1aA
80 kg ha^{-1} soluble phosphate	15.6aA	12.0bA	59.0aA	49.8aA	46.8aA	48.1aA
			5–10-cm soil depth			
0 kg ha^{-1}	13.9aA	10.2aB	32.6aA	33.4aA	42.2aA	45.7aA
80 kg ha^{-1} reactive phosphate	17.7aA	16.8aA	31.6aA	32.3aA	49.7aA	48.9aA
80 kg ha^{-1} soluble phosphate	12.2aA	16.8aA	40.5aA	32.9aA	48.2aA	42.1aA

[(1)]P fractions as in Hedley et al. (1982) fractionation: 0.5 mol L^{-1} $NaHCO_3$-Po, available Po; and 0.1 mol L^{-1} NaOH-Po and 0.5 mol L^{-1} NaOH-Po, less available forms of PO. [(2)]Means followed by equal letters, lowercase between ruzigrass treatments and uppercase between P treatments, do not differ by LSD test, at 5% probability.

For Po fractions, the interaction occurred only for 0.5 mol L^{-1} $NaHCO_3$ extractable Po, at the 0–5 cm soil layer.

Phosphorus fertilization increased soybean yield and its P content in leaves. (Table 4). However, ruzigrass cultivation had no effect on soybean yield, but increased P content in leaves. In general, P contents were low compared with the adequate range (over 2.5 g kg^{-1}), as reported by Rosolem & Boaretto (1989). Its deficiency was more severe and common in plots without fertilizer and ruzigrass. Ruzigrass and P sources did not interact as to soybean yields and leaf-P contents. Francisco et al. (2007) reported that P fertilization of increased finger millet (*Eleusine coracana*) biomass production, but had no effect on subsequent soybean yield.

The original soil P values (17.2 mg dm^{-3} of resin-P), down to 10 cm, was probably sufficient for ruzigrass growth, since there was no response of P fertilization as to nutrient contents on leaves and dry matter yield. Similarly, Horowitz & Meurer (2004) found no differences in the response of the genus *Urochloa* to natural and soluble P sources, as to biomass yield and plant-P concentration. This shows that the species is well adapted to soils with low natural fertility.

The observed buildup of available P in the topsoil due to ruzigrass cultivation agrees with the findings of Pavinato et al. (2009). This effect may result from the role of organic acids on P sorption, since ruzigrass can exude citrate or oxalate under low pH conditions (Louw-Gaume et al., 2010). Low molecular-weight organic acids, such as those, complex soil Al and compete for P exchanging sites, resulting in less P sorption in the soil (Pavinato & Rosolem, 2008). Low-P supply enhances the activities of phytases and root acid phosphatases in some grasses (Rao et al., 1999).

Soil P extracted with 0.1 mol L^{-1} NaOH was not affected by ruzigrass or P sources (Table 2). Gatiboni et al. (2007) observed no changes in soil-P fractions as affected by fertilization, whereas Silva et al. (2003) observed significant decreases in Fe/Al-P after growing *Urochloa* sp. in a pot experiment, due to high P uptake by grass. In pot experiments, plant roots are so densely distributed that nearly all soil in the pots are close to the rhizosphere, where pH is usually lower, and P availability may be higher. This may explain the effect observed by Silva et al. (2003).

Ruzigrass cultivation also affected Ca-Pi, extracted with 1 mol L^{-1} HCl, in the uppermost soil layer, when RRP was applied (Table 2). This result can be partially explained by the Ca level in Arad phosphate (37%), which is higher than that of triple superphosphate (13%). Moreover, some of the undissolved RRP might add to the extracted Ca-P, as evidenced by higher Ca-P in the 0–5 cm soil depth of plots. Similar results were obtained by Rodrigues et al. (2009), which observed increases in Ca-P after RRP application. The effect of ruzigrass in reducing Ca-P, in soluble phosphate plots, is likely related to the utilization of this P fraction by the cover crop.

The increase in 0.5 mol L^{-1} $NaHCO_3$ extractable Po (Table 3), due to ruzigrass cultivation, can be attributed to the exudation of some Po or from a more intense cycling of plant residues. Similar result was reported by Silva et al. (2003). Organic P constitutes a signifcant portion of total P, ranging from 15 to 80% in most soils (Stevenson, 1982), and it contributes substantially to plant-available P. $NaHCO_3$ extractable Po, although not directly absorbed by plant, is generally considered to be readily or potentially available to plants because of its low molecular weight and prone to readily mineralization (Hedley et al., 1982; Gatiboni et al., 2007).

The results found here indicate that *U. ruziziensis* cultivation as cover crop can enhance P availability in soils with high-P fixation capacity. Further research is required to identify which mechanisms are involved in assessing less labile P forms by the cover crop.

Table 4. Soybean yield and P content in leaves as affected by broadcast application of phosphorus sources and by *Urochloa ruziziensis* cultivation[(1)].

Treatment	Yield (kg ha^{-1})			P content (g kg^{-1})		
	With *U. ruziziensis*	Without *U. ruziziensis*	Phosphate average	With *U. ruziziensis*	Without *U. ruziziensis*	Phosphate average
0 kg ha^{-1}	2.672	2.566	2.619b	2.0	1.7	1.9b
80 kg ha^{-1} reactive phosphate	3.101	3.082	3.092a	2.2	2.1	2.2a
80 kg ha^{-1} soluble phosphate	3.050	3.037	3.044a	2.4	2.2	2.3a
Ruzigrass average	2.941	2.895	-	2.2A	2.0B	-

[(1)]Means followed by equal letters do not differ by LSD test, at 5% probability.

Conclusions

1. Ruzigrass cultivation increases soil-P availability, regardless of the P source, especially where corrective P fertilization is performed.

2. The use of ruzigrass as cover crop has no significant effect on subsequent soybean yield.

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